MWCNT/EPOXY COMPOSITE FILM AS A STRUCTURAL STRAIN SENSOR FOR MICRO AIR VEHICLES

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Abstract

Peizo resistive Multiwall Carbon Nano Tubes (MWCNT) /Epoxy based composites film sensors with varying percentage of MWCNTs were developed and the percolation behaviour was studied by electrical conductivity measurements. These films exhibited percolation thresh hold at 2% MWCNT loading. Further, the composite film sensors were characterized in quasi static tensile mode in the range 0-1300 micro strain using a custom designed electrical circuit. The sensitivity of the various composite sensors, estimated in terms of gauge factor was found to be in the range of 40-140 for different percentage loading of MWCNT. To explore the feasibility of these sensors for Micro Air Vehicles (MAVs), static test was carried out by mounting the composite film sensors on MAV wing. The response of the film sensor for bending induced tensile and compressive strains was investigated. Gauge factors of 90 and 80 were realized for tensile and compressive strains respectively. These studies indicated that MWCNT/ Epoxy based composite films are found to be promising candidate for structural strain sensing on MAV.

Introduction

Conventional strain gauges (metal and semiconductor strain gauges) being inexpensive and easy to handle are the most preferred devices for structural strain sensing. However, the usage is limited to read the strain in specific direction. Further, they have low resolution at nano scale and cannot be embedded in structural materials. Fibre Bragg Grating (FBG) sensors can be embedded into composites or can be fixed directly or as patches on the surface of the structural materials like normal strain gauges. They can measure very high strain (>10,000μm/m) and are well suited to highly stressed composites constructions but are insensitive to strain on a nanoscale [1].

Carbon nanotube based composites are increasingly gaining importance as realistic alternative materials to conventional strain gauges due to their higher sensitivity [2-4]. The

CNT undergoes structural change under applied strain [5]. This change can be characterized by Raman spectroscopy [6]. However, for practical application like sensing the strain on the surface of a structure, calibration of the Raman spectrum shift with mechanical strain is essential . Realization of this concept calls for the assembly of complex equipments which remains a challenge [7]. Since CNTs are peizo resistive in nature, polymer/carbon nano tubes composite based thin films can serve as good alternatives for developing new sensors because of their outstanding properties [8-15]. These thin film strain sensors can be embedded into structural materials and operate as both multidirectional and multifunctional sensors with high strain resolution on nano scale [3, 16-19].

Over past several years there has been increasing research interest for implementing morphing and flapping concepts in micro air vehicles [20]. These concepts involve a design that integrates innovative combination of materials and mechanisms to adapt to different flight regimes. Such features when incorporated in to the structure increase the efficiency and performance of the vehicle. Strain sensors with high sensitivity are essential in optimizing the mission profile of Micro Air Vehicle (MAV) and thereby ensuring the safety of the vehicle too. Carbon nanotube based film sensors owing to their superior sensitivity and resolution as compared to metal foil strain gauge and FBG is a potential candidate for sensing low magnitude strains typically encountered by MAV's [21].

In the present work MWCNT/Epoxy based composite films were developed and the percolation behaviour was studied. Subsequently the electrical resistivity of these composites films tailored to 12mm*10mm*0.1mm, under tensile strain were measured in situ using laboratory designed fixtures and data acquisition systems. The sensitivity /gauge factor was estimated from the measured resistivity and applied strain. Composite film sensor with 10% MWCNT was mounted on MAV wing and characterized under bending induced tension and compression. This paper highlights the development and characterization of MWCNT/Epoxy composite film as a structural strain sensor for.

Development of MWCNT/Epoxy composite films :

Multiwall Carbon nano tubes of diameter: 10-20nm, length 5-40µm, purity >90%, SSA: >200m^2/gm and Amorphous carbon: <5% procured from -M/s. Intelligent Materials, USA and Epoxy resin system procured from - M/s. Southfield Paints Ltd., Bangalore were used to prepare the composite film sensors.

MWCNTs were dispersed into Epoxy resin by using a high power ultra sonicator for 10 minutes initially followed by planetary mixing using Thinky ARE 310 mixer .The Epoxy hardener was added to the MWCNT dispersed epoxy resin and the stoichiometry of the resin to hardner was maintained as 1:1. This mixture was further subjected to planetary mixing for better dispersion. This mixture was spread over the active surface of an auto film applicator for preparing the composite films The film was dried for 24hr at room temperature. The film dimensions were maintained as 70*70*0.1 mm. Figure 1 shows the typical film developed by auto film applicator.

Figure 1 MWCNT/Epoxy film

Percolation studies:

The composite conductivity dependence on filler concentration is often described by the percolation theory. When the filler concentration reaches a critical value, there are enough filler to form an infinite network in the composite matrix, and the conductivity of the composite will experience a dramatic change. This concentration of the filler is called as percolation threshold [22-26]. The percolation threshold of MWCNT/Epoxy system can be identified by measuring the electrical conductivity of films with varied MWCNT loadings. The conductivity measurements were done by using Keithley 8009 Resistivity chamber which was interfaced with keithley 6517B Electrometer, and supported by a keithley 6524 high resistivity measurement software programme. Figure 2 shows the test set up for electrical conductivity measurement

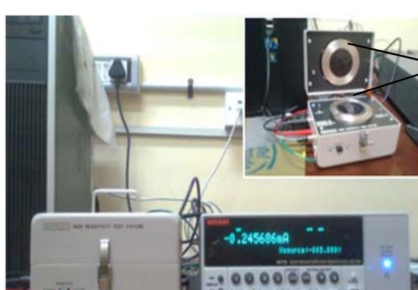

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Figure 2 Test set up for electrical conductivity measurement

The measured conductivities were plotted against the percentage of MWCNT loadings as shown in figure 3 below

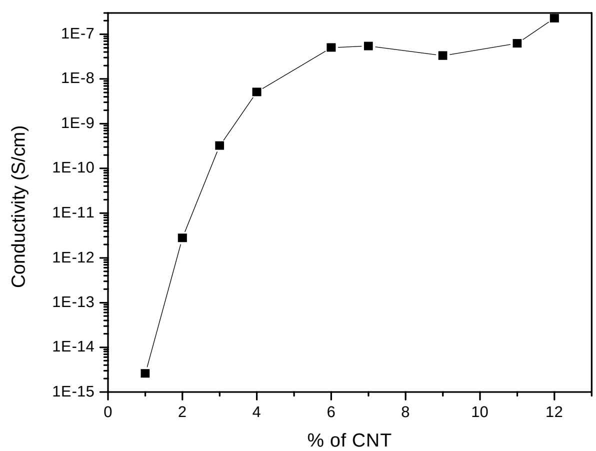


Figure3. Percolation graph

From the graph the percolation threshold was found to be 2%. Depending on the type of polymer matrix and processing technology as well as the type of CNT materials used, percolation thresholds ranging from less than 1.0% to over 10.0 wt.% of CNTs loading have been reported in literature {13-14} . Most of the strain-sensing experiments were conducted at percolation threshold. In the present study an attempt was made to investigate the effect of CNT loading on sensor behaviour beyond percolation threshold. Hence composite film sensors were fabricated with CNT loadings in the range 2-12%

Circuit development for Strain sensing:

Wheatstone bridge circuit is more suitable for strain gauges whose initial resistance is constant(120 and 350Ω). However, as initial resistance varied within a range from sample to sample of the composite film sensor it became difficult to use Wheatstone bridge, Therefore, a modified Wheatstone bridge was designed and developed. In this bridge the balancing was done externally to suit CNT sensor. Figure 4 represents the block diagram of the circuit.

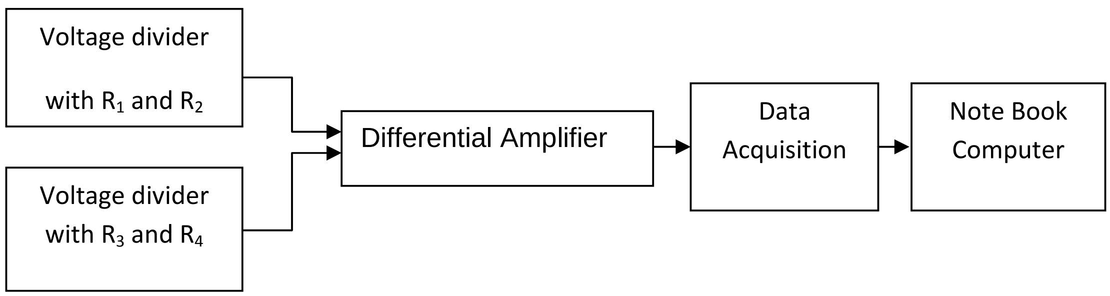


Figure 4 Block diagram of modified Wheatstone bridge

This circuit consists of voltage divider, differential amplifier, data acquisition and note book computer. In the circuit the R2 represents the CNT sensor. The resistor R1 was selected to match the initial resistance of the CNT before loading. The resistors R3 and R4 together constitute a multi turn potentiometer used to subtract the voltage drop across R1 so that the measure voltage will correspond to voltage across the CNT sensor R2 . Both the voltage divider circuits were excited with 5V supply. These two voltages were fed to the differential amplifier to obtain the voltage difference between the two voltage divider circuits. The potentiometer was adjusted in such a way that the differential amplifier output voltage was zero .The change in voltage due to applied strain/load was acquired using a NI based data acquisition system.

Strain sensing characterization:

MWCNT/Epoxy composite films were cut into 12*10 mm size and adhered on to the top of brass specimen (200*10*3 mm) using adhesive for perfect strain transfer and for electrical insulation. The initial resistance of the film was measured by the circuit developed. The strain gauge was mounted on the other side of the brass specimen for strain measurement and comparison. This brass specimen was loaded in the universal testing machine and subjected to axial tensile strain.   Figure 5 shows the test set up for the strain sensing characterization.

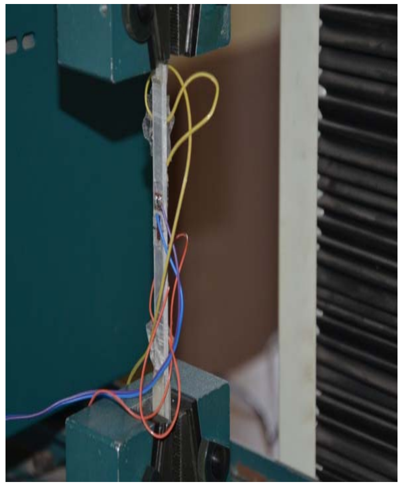
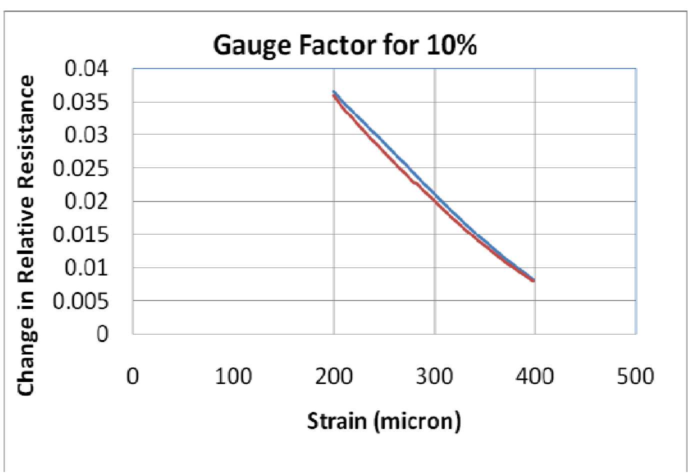


Figure 5Test set up for the strain sensing characterization.

The change in resistance in composite film sensor and strain from conventional strain gauge were acquired simultaneously. The change in relative resistance of the CNT sensor was correlated with the strain recorded from conventional strain gauge. The gauge factor of the CNT sensor was estimated by plotting the change in relative resistance against the applied strain as shown in shown in figure 6. Table 1 presents the gauge factor estimated for various CNT film sensors



$$K = \frac{\Delta R/R}{\varepsilon} = 100$$

Figure 6 Gauge factor estimation

.Table 1 : Gauge factor estimated for CNT/Epoxy sensors

Percentage of Loading of CNT	Gauge Factor
2	122
6	140
10	100
12	40

Static load test on the MAV wing (Wind tunnel model):

In order to investigate the response of sensor on MAV, CNT sensor films of 12*10mm were pasted towards one side of the centerline of MAV where the fuselage meets the wing. Five CNT sensors were placed on MAV from front to rear side and an equal number of conventional strain gauges were placed symmetrically on the other side of centerline as shown in figure 7a &b. Initial resistances of all the five CNT/Epoxy sensor were measured. Rubber pads each weighing around 60gm were loaded at an interval of 10sec to cover half the plan area of wing. The voltage from CNT sensor and strain from conventional strain gauge were acquired simultaneously during loading and unloading as shown in figure 8 .From the figure it is seen that MWCNT/Epoxy polymer composite film sensor responds for the loading and unloading phases. The response of the sensor for bending induced tensile strain and compressive strains were characterized. The change in relative resistance of the CNT sensor was calculated and correlated with conventional strain gauge and the gauge factor of the CNT sensor was estimated as shown in figure 9.Table 2 below shows the gauge factor realized for different modes.

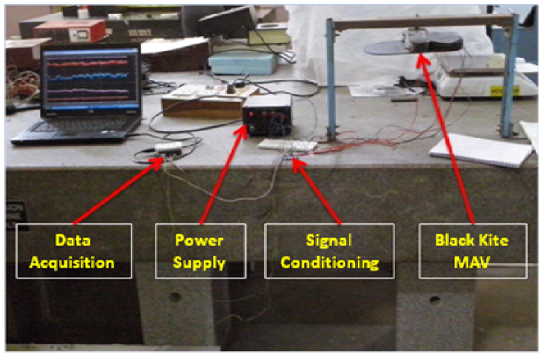
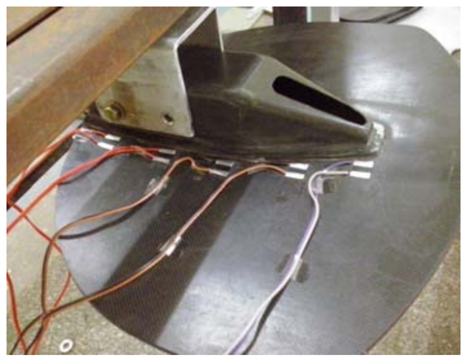


Figure 7(a) Static load test setup on the MAV wing (Wind tunnel model)



7 (b) Closer view of CNT Sensors on MAV

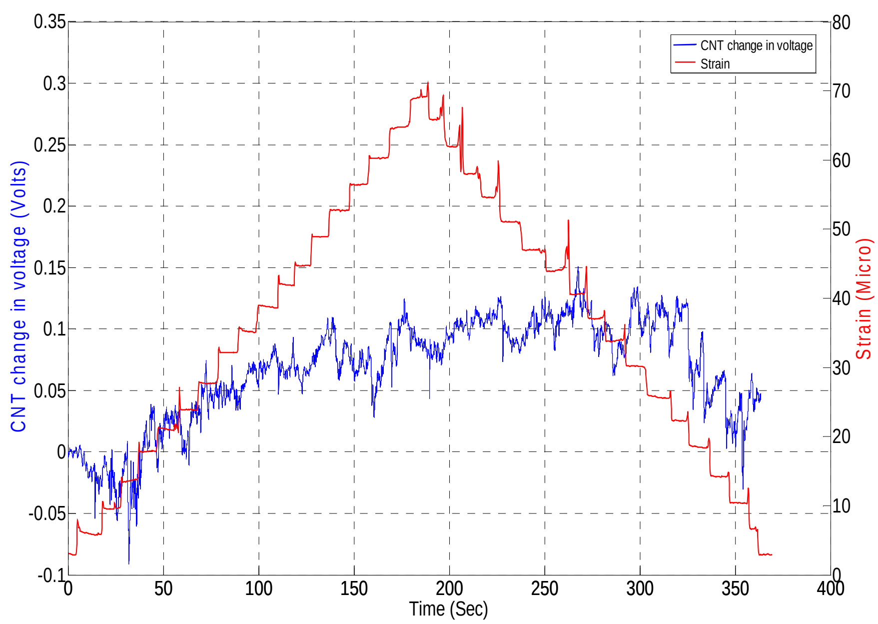
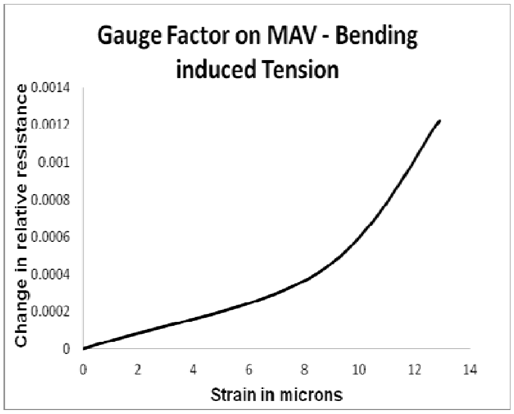


Figure 8 Response of MWCNT/Epoxy sensor and strain gauge on MAV



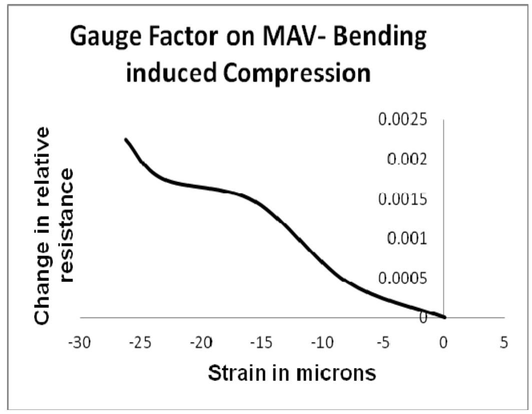


Figure9 Estimation of gauge factor on MAV in bending induced tension and Compression modes

Table 2 Comparison of Gauge factor for CNT sensor film mounted on MAV in Tension and compression mode.

MAV Wind Tunnel Model	Gauge Factor
Bending induced Tension	90
Bending induced Compression	80

Conclusion:

Our studies indicated that MWCNT/Epoxy composite films are effective in strain sensing. The sensitivity of these sensors were found to be two orders higher than the conventional strain gauges. The high gauge factor values obtained in the range 40-140 in uniaxial tension and bending for various film sensors indicate the merit of MWCNT/Epoxy composite films over conventional strain gauge for high strain resolution in nano scale. Hence as the case with conventional strain gauges these sensors can be configured (in rosette configuration) to sense strains under uniaxial tension, compression, bending and torsional strains. Further, the sensor was found to be responding to the loads encountered by MAV during different flight regimes. Hence it is a potential candidate for sensing low magnitude strains typically encountered by MAV's.

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